Vayu Mandal 43(1), 2017

Climate Change Adaptation in Agriculture in India

Akhilesh Gupta, V.Geethalakshmi*, Nisha Mendiratta, Himanshu Pathak**, and Mamta Sharma***

Climate Change Programme,
Department of Science & Technology, New Delhi
**Tamil Nadu Agricultural University, Coimbatore*
***National Rice Research Institute, Cuttack*
****International Crops Research Institute for the Semi-Arid Tropics, Hyderabad*
Email: akhilesh.g@nic.in

ABSTRACT

Indian agriculture has made a significant progress in recent years, but of late it is facing many challenges due to the adverse effect of climate change. Moreover, the increasing population pressurizes the agricultural sector for enhanced food production. To face the challenges of food security and climate change, the country needs to reorient its land use and agriculture with the state-of-the-art technologies and policy initiatives. DST through its research initiatives, has partnered with three institutions viz., Tamil Nadu Agricultural University, Coimbatore; International Crop Research Institute on Semi-Arid Tropics, Hyderabad and Indian Agricultural Research Institute, New Delhi to develop potential techniques and technologies for adaptation in agriculture to increase resilience against climate change in sustaining crop production. The paper briefly presents outcome of these studies.

Keywords: *Climate Change, Agriculture, Assessment, Projection, Adaptation, Mitigation and Resilience.*

1. Introduction

Agriculture is crucial for ensuring food, nutrition and livelihood securities for India. Global climate change has considerable impact on the crops, soils, livestock and pests. In the last 100 years the mean annual surface air temperature of India has increased by 0.4-0.6°C (Rupakumar, 2002). Annamalai (2010) reported decreasing rainfall tendency in both southwest and northeast monsoon seasons in most parts of central and northern India. Future climate projections through the CMIP5-based model ensemble projects a warming of 2.8°C and 4.3°C over India under the RCP6.0 and RCP8.5 scenarios respectively, for 2080s compared to the 1970s baseline (Rajiv Kumar *et al.* 2012). According to Khan *et al.* (2009), the mean rainfall of India for the SRES is projected to increase by 10% during *Kharif* and *Rabi* seasons during 2070 from the reference year 2010.

To address the food security issues, under the National Action Plan on Climate Change (NAPCC), the Government of India has launched eight National Missions during the XII Five year plan. The National Mission for Sustainable Agriculture (NMSA) and the National Mission on Strategic Knowledge for Climate Change (NMSKCC) are targeted to achieve an agricultural growth rate of 4% per annum and also enable the country to cope with the impacts of a changing climate. Under the NMSKCC, the Department of Science & Technology (DST) has supported several projects in the area of climate change and agriculture. Three such projects were given to Tamil Nadu Agricultural University (TNAU), Coimbatore; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad and Indian Agricultural Research Institute (IARI), New Delhi to undertake research on the impact of climate change on agriculture for developing appropriate adaptation strategies including strategic knowledge. Methodology and results derived from specific case studies undertaken from the above institutions are presented in this paper.

2. Methodology

2.1 Influence of ENSO on rainfall over Tamil Nadu:

Influence of ENSO on rainfall over Tamil Nadu was examined by performing simultaneous correlation and lag correlation between SOI rainfall. Historical SOI values were segregated into Neutral (-5.5>SOI <+ 5.5), El-Nino (SOI$\leq$-5.5), La Nina (SOI$\geq$+5.5) to correlate with gridded daily rainfall data at 0.5 x 0.5 degree resolution accumulated for Southwest and Northeast monsoon seasons over Tamil Nadu.

2.2 Climate change impact assessment

2.2.1 Simulating impacts of climate change on crop productivity:

A simulation analysis was done to assess the impacts of climate change on rice, wheat, mustard and potato crops in the IGP region. The adaptation gains and vulnerable regions also are derived. The analysis was done using MIROC and PRECIS scenarios and the InfoCrop model for three time slices (2020 -2010-2039; 2050-2040-2069; 2080-2070-2099).

2.2.2 Study on the response of C_3 (Rice) and C_4 (Maize) plants to elevated temperature and CO_2

Impact on C_3 (rice) and C_4 (maize) plants to elevated temperature and CO_2 were studied under ambient (T1) as well as controlled condition using Temperature Control Chamber (T2) (TCC: ambient temperature + 4°C) and Soil Plant Atmosphere Research (T3) (SPAR: ambient temperature + 4°C and 550 ppm CO_2).

2.2.3 Integrated assessment of climate change impact on hydrology and rice productivity over Cauvery basin.

Various climate change scenarios perceived by the IPCC was modelled to study the impact on the hydrology and water availability using hydrological models. For getting future climate data at closure grid size (25 x 25 km), ensemble of 16 GCMs were used. Soil and Water Assessment Tool (SWAT) was employed to map the hydrology of the Cauvery basin for baseline and future climate scenarios. The outcome of the climate and SWAT models were coupled with dynamic crop simulation model (DSSAT: Decision Support System for Agro-technology transfer) to study the impact of water availability and changing climate on crop productivity. These impact models were calibrated and validated for the Cauvery delta region before it was employed for impact assessment. Based on the model outputs, various adaptation technologies were designed to improve the water and nutrient use efficiencies.

2.2.4 Impact of climate change on pest

Climate change facilities such as Open Top Chambers (OTC), Free Air Carbon Dioxide Enrichment (FACE), and CO_2 incubators with precise CO_2, temperature and relative humidity controlled incubators to undertake research on the interaction of host plant with the specific pests and pathogens were established at ICRISAT-Patancheru, Hyderabad.

2.3 Development of adaptation options

(i) Screening of cultivars for climate change

Screening of cultivars of rice, wheat and maize was done for abiotic and biotic stress tolerance under controlled condition. Varieties of different duration were taken and staggered planting was done to coincide the flowering period of all the varieties under the study to understand the influence of the elevated temperature. Same varieties were also grown under ambient conditions for comparison purpose. Apart from this, various other adaptation options were designed and field tested.

3. Results and Discussion

3.1 Influence of ENSO on rainfall over Tamil Nadu

El-Nino Southern Oscillation influenced Tamil Nadu rainfall, correlation results indicated that the weak El-Nino years (SOI between -5.5 and -10) had positive correlation with SWM rainfall of southern, central and northwestern parts of Tamil Nadu. In strong El-Nino years (SOI between -10 and -35), a positive correlation was observed in the eastern and northeastern parts of Tamil Nadu as well as in most parts of the eastern coast. All La-Nina years had positive correlation with SWM rainfall over most parts of Western Ghats and northern coastal area. Weak El-Nino years had positive correlation with SWM rainfall over southern parts of Western Ghats and central Tamil Nadu. Strong El-Nino years had the positive relationship with rainfall covering the whole of Western Ghats and eastern coast (Fig. 1).

As far as NEM is concerned, only southern Tamil Nadu showed correlation upto 0.4 with El-Nino condition, while all other parts had weak correlation. Weak El-Nino years had good negative relationship with NEM rainfall over entire Western Ghats, east coast and northern pockets of Tamil Nadu. In contrast, strong El-Nino years exhibited positive correlation with northern and central Tamil Nadu including eastern coast for NEM rainfall. In all La-Nina years, northern and central Tamil Nadu showed negative relationship while in weak La-Nina years, the negative relationship with NEM rainfall extended to total Tamil Nadu except few parts of western and northern regions of Tamil Nadu. In strong la-Nina years, except Cauvery basin all other parts showed positive relationship with NEM rainfall (Fig. 1). It is clear from the above analysis that the strength of the El-Nino could be effectively used for predicting the rainfall over different regions of Tamil Nadu.

3.2 Climate change impact assessment

3.2.1 Impacts of climate change on crop productivity

Rice: At regional level, states like Punjab, Haryana and Rajasthan are projected to lose more yields (6–8 %) in the 2020 scenario. Similarly in the 2050 scenario, projected yield loss is expected to stand at 15–17 % in the above three states. Regions that are adversely affected can have net improvement in yield in future scenarios with adaptation (most of irrigated rice areas of west and north India).

Wheat: The results indicated that among the wheat-growing regions, the impact of climate change on yield is projected to vary spatially, and with climate and emission scenario. By 2050, wheat yield in north-western IGP (NWIGP), consisting of the states of Punjab and Haryana, is projected to decrease 8 to 22%, with a greater reduction in Haryana.

Mustard: At the regional level (Fig 2), states like Punjab and Haryana are projected to have increased yield in 2020. In other parts of north India (Uttar Pradesh, Bihar and Assam), yields are projected to reduce up to 6%. Projected yield reduction in north India is 0.5–4% in 2020, 3–10% in 2050 and 12–23% in 2080. A combination of improved input efficiency, 25% additional N, and adjusting the sowing time can increase the yields by ∼17% with current varieties and by ∼25% with improved varieties in 2020. These benefits are projected to progressively reduce beyond 2020.

Potato: The potato crop duration in the IGP is projected to decrease due to climate change. The evapotranspiration (ET) is projected to increase while the water use efficiency`(WUE) for potato

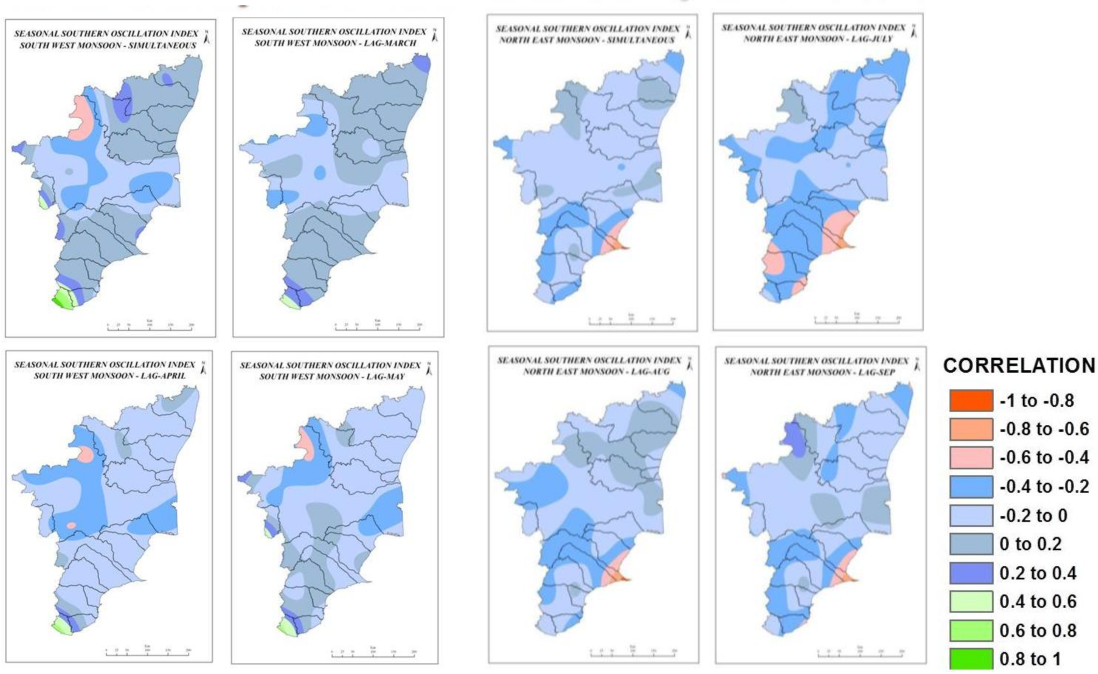

Figure.1 SOI simultaneous and Lag correlation with SWM and NEM rainfall

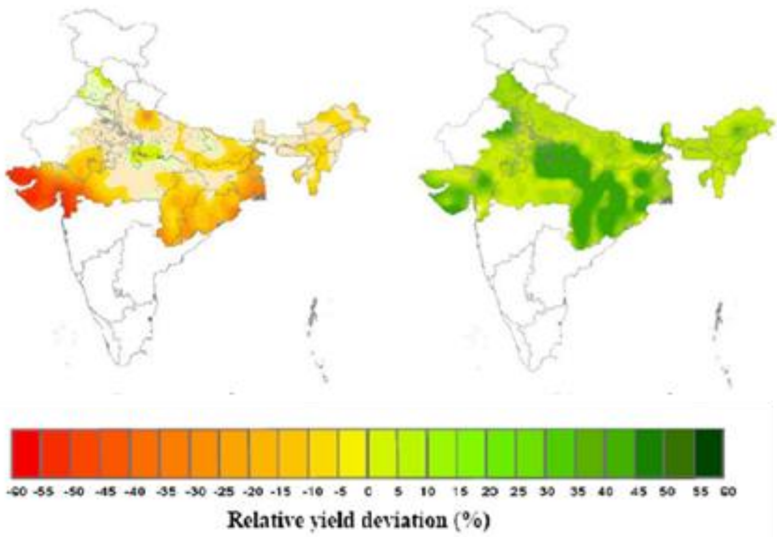

Figure.2 Impact of climate change on mustard yield (a) and adaptation gains (b) in 2020 scenario.

yield is projected to decline in future climates as a consequence of low threshold temperatures for decline in WUE and yield than the ET. Results indicate that the upper threshold for ET decrease is ~23 °C while that for WUE is 15 °C. The optimal temperatures for tuber yield is ~17 °C and thus the reduction in WUE in future climates is discernable. Climate change is projected to reduce potato yields by ~2.5, ~6 and ~11% in the IGP region in 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099) time periods.

3.2.2 Response of C_3 (Rice) and C_4 (Maize) plants to elevated temperature and CO_2

Impact on C_3 (rice) and C_4 (maize) plants to elevated temperature and CO_2 indicated that increase in temperature with or without CO_2 enrichment affected the phenology and productivity of C_3 and C_4 plants with different magnitude. Temperature increase alone had negatively affected the C_3 crop (rice) more compared to C_4 crop (maize). However, CO_2 enrichment had compensated the negative impact of elevated temperature to certain extent. Rice had responded more positively to CO_2 enrichment compared to maize under elevated temperature (Table 1).

Table 1. Effect of ambient and controlled conditions on yield of rice and maize
(T1: Ambient condition; T2: Ambient temperature + 4°C; T3: Ambient temperature + 4°C and 550 ppm $CO_{2.}$)

Treatments	RICE (C_3)				MAIZE(C_4)			
	Grain yield (g / plant)	Straw yield (g / plant)	DMP (g / plant)	Grain conversion %	Grain yield (g / plant)	Straw yield (g / plant)	DMP (g / plant)	Grain conversion %
$T_{1\ (Ctrl)}$	38.15	51.12	93.00	41.02	107.25	152.34	270.59	39.64
$T_{2\ (TCC)}$	21.00 (-45%)	39.06 (-23%)	65.13 (-30.3%)	32.31 (-21.0%)	80.88 (-24%)	133.66 (-12%)	223.55 (-17.4%)	36.18 (-21.0%)
$T_{3\ (SPAR)}$	24.68 (-35%)	47.63 (-15%)	71.06 (-23.7%)	33.78 (-15.3%)	84.59 (-21%)	138.31 (-9.2%)	232.14 (-14.2%)	36.54 (-15.3%)
SEd	0.1713	0.284	0.4643		0.5507	0.8609	1.47	
CD (p=0.01)	0.4931	0.818	1.3363		1.5855	2.4785	4.2319	

3.2.3 Integrated assessment of climate change impact on hydrology and rice productivity over Cauvery basin.

Future climate predictions derived from the ensemble of 16 GCMs for Cauvery basin indicated the increase in rainfall between 7 and 21% towards mid-century (2040 -2069) while this increase is projected to be between 10 and 3% in end century (2070-2099) compared to baseline (1971-2005). Temperature is expected to increase by 1.5 to 2 ^{0}C and 3 to 4.5 ^{0}C in the mid and end century time scale. The SWAT model was calibrated and validated and the model could predict the stream flow and yield very well (Fig. 3).

The SWAT model results showed that in the mid century, the predicted increase in annual Potential Evapotranspiration (PET) for Cauvery basin would vary from 3 to 4.5% and 8.4 to 9.3% for the mid and end century scenario respectively over the present level. Annual water yield is expected to increase by 14 to 21% during mid-century and is projected to increase further by 20 to 27% towards end century. The annual soil water storage is also predicted to increase by 5 to 14 % and 7 to 18% in the mid and end century respectively.

Climate change impacts on irrigation water requirement for paddy: Results of SWAT model indicated that climate change impacted the atmospheric water demand and irrigation water requirement of paddy in the delta portion of Cauvery basin in Tamil Nadu. PET is expected to increase in the mid and end century. As a result of this water requirement of rice crop is also expected to increase in future (Fig. 4).

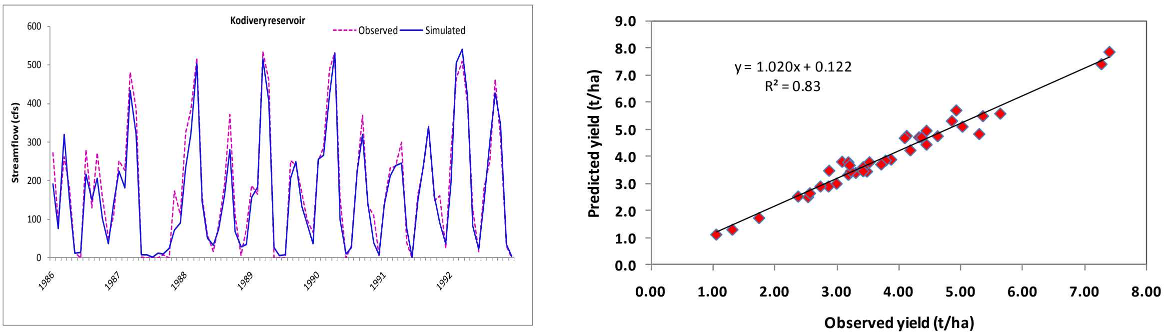

Figure. 3. Comparison of observed and SWAT simulated crop yield and stream flow over Cauvery basin

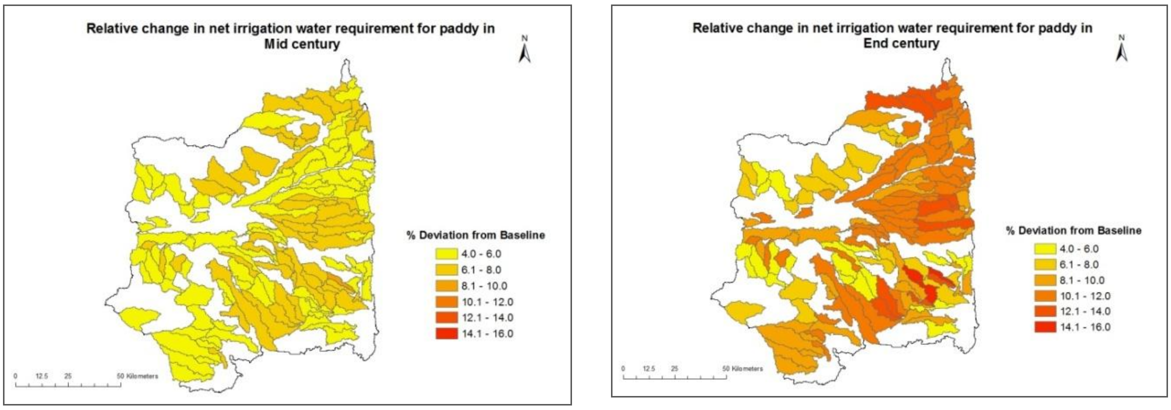

Figure. 4. Changes (%) in irrigation water requirement for paddy during mid and end century compared to the baseline

3.2.4 Impacts of climate change on BPH in rice

Temperature sensitivity analysis: The BPH population simulation model was developed based on thermal constant, threshold of development, and abiotic and biotic mortality factors and coupled to InfoCrop model. 0.5 to 3.0 ^{o}C rise in *kharif* showed 1.5 to 25.2% population decline. In climate change scenario 2020 (0.87-1.17 ^{o}C rise), BPH population declined by 3-4% and in 2050 (1.81-2.37 ^{o}C rise) it declined by 9-14% (Fig. 5).

CO_2 impacts: When the BPH was exposed to elevated CO_2 (570 ±25 ppm), it enhanced the multiplication rate (72.7±16.2 hoppers/hill) compared to ambient CO_2 (32.6±4.7 hoppers/hill). Higher BPH population due to greater fecundity under elevated CO_2 resulted in higher yield loss (26.5%) than ambient CO_2 (12.4%). The sucking rate of the BPH was also higher under elevated CO_2.

3.3 Designing innovative adaptation technologies

3.3.1 Screening crop cultivars for elevated temperature

Rice genotypes for thermal stress: In rice crop, ADT 40, Vellai samba and karthigai samba cultivars recorded highest spikelet fertility in control chamber (with 5^{0}C elevated temperature) compared to open condition. Among the 18 long duration rice cultivars, vellai samba and karthigai samba exhibited higher tolerance to

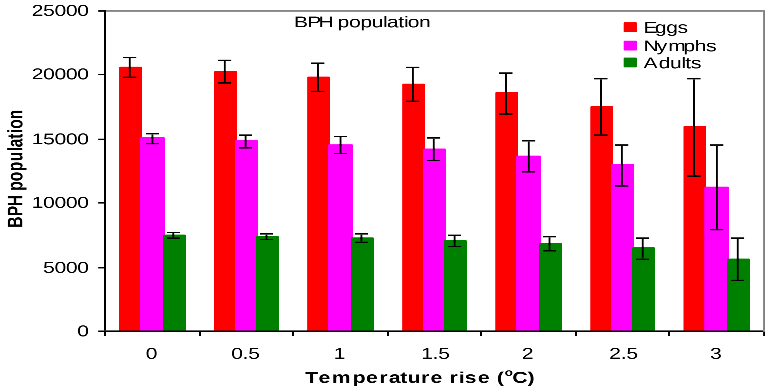

Figure. 5. Simulation of Brown Plant hopper (BPH) population with increased temperature.

elevated temperature (upto 43 ^{0}C) and these varieties could be used in the breeding programmes for developing heat tolerant cultivars.

Wheat genotypes for thermal stress: Four promising wheat cultivars of short (WR 544 and HD 2285), medium (HD 2932) and long (HD 2967) growth duration were grown from October to January at 15 days interval to expose the crop to high thermal stresses. All the wheat cultivars irrespective of their growth duration registered poor yield when subjected to initial and terminal heat stresses. Among the cultivars, the medium and long duration wheat cultivars (HD 2932 and HD 2967) invariably recorded higher yield both under normal as well as under early and late sown conditions, whereas the short duration cv. HD 2285 performed well under extreme late sown condition. Reduction in yield by initial heat stress was mainly attributed to marked reduction in spikes/m^2, while terminal heat stress caused drastic reduction in yield mainly by reducing the growth duration, grains/spike and 1000 grain weight. Both initial and terminal heat stresses hastened flowering in all the cultivars, while, total days to maturity reduced gradually with delayed sowing. It is concluded that short duration cultivars may be suitable only for late sowing, while long duration cultivars may perform better both under early and late sown condition especially under mild terminal heat stress condition.

Wheat germplasms for proline accumulation: Proline accumulation has been considered as one of the most important trait for protecting the internal metabolic system under drought and heat stress. Seventy three different wheat lines grown under net-house were used for the proline estimation at grain filling stage (samples were collected based on the Feeke scale). Maximum proline accumulation was observed in C306, Kundan and Halna, whereas minimum was observed in UP2648 and UP2647. Most of the thermo tolerant lines were observed to be good proline accumulators, whereas thermo susceptible lines showed very low accumulation of proline (Fig. 6).

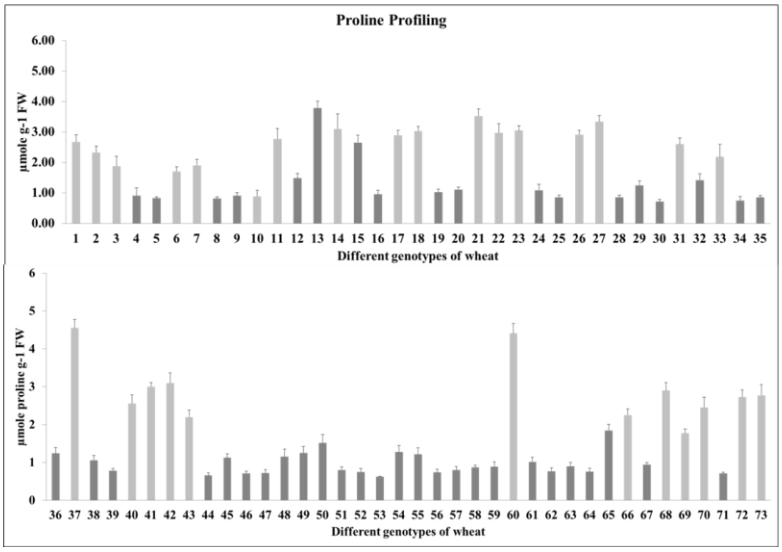

Figure. 6. Proline profile of different wheat genotypes.

Screening of wheat germplasm for total antioxidant capacity: Total antioxidant capacity (TAC) has been selected as one of the most promising parameters for screening wheat germplasm for thermo-tolerance. Studied the variations in the TAC in 73 different wheat germplasm grown under net-house condition at grain-filling stage (selected based on Feeke scale). HD 2781 showed maximum TAC value followed by HD 3059 and HD 3090. The TAC was observed minimum in K 9423 followed by UP 2338 and UP 2748. Most of the cultivars which showed high yield under terminal HS showed high TAC value compared to cultivars sensitive to HS where there was low value of TAC. To conclude, cultivars having high proline accumulation and TAC value had high thermo tolerance capacity and withstand the terminal HS during grain-filling stage without compromising with the yield (Fig 7).

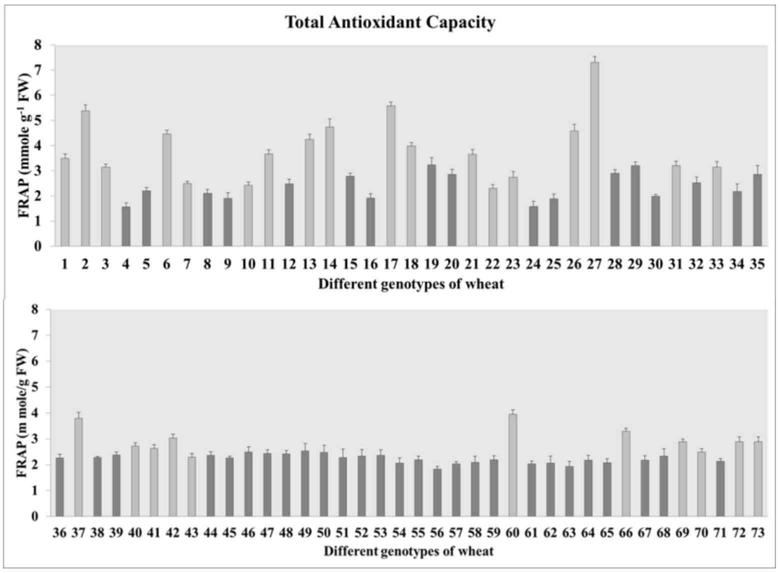

Fig. 7. Antioxidant capacity of different wheat genotypes.

3.3.2 SRI as an adaptation technology to changing climate in rice

Simulation of well calibrated and validated DSSAT- CERES- Rice model indicated that the rice crop would be greatly affected due to changing climate and the yield is expected to go down under future warmer climatic condition. Some of the adaptation technologies like timely planting and practicing system of rice intensification (SRI) would help in sustaining the rice yields under changing climatic condition. During *Kharif* season, SRI produced higher yield by 33.1% (25.1 %) with water saving of 16% (7.8 %) over traditional flooded rice cultivation.

3.3.3 Identification of best planting window

Rice: Rice crop grown under climate control chamber with elevated temperature (ambient +4°C) and CO_2 enrichment (650 ppm) recorded reduced growth characters such as number of tillers, leaf area index and dry matter production. It has also recorded lower grain and straw yields due to lesser number of productive tillers and lesser number of filled grains. Crop planted on 1st June registered higher growth characters like stem height, number of tillers, leaf area index and dry matter production than other dates of sowing. Among the different sowing windows tested to manage climate change, 1st June sowing yielded more than advanced or delayed planting under both ambient as well as under modified climatic conditions.

Potato: Change in planting time is the single most important adaptation option which may lead to yield gains by ~6% in2020 and its combination with improved variety or additional nitrogen may be required to adapt to climate change leading to positive gains by ~8% in 2020 and by ~5% even in 2050. However, in 2080 adoption of all the three adaptation strategies may be needed for positive gains. Intra-regional differences in the impact of climate change and adaptation gains are projected; positive impact in northwestern IGP, gains in Central IGP with adaptation and yield loss in eastern IGP even with adaptation (Fig 8).

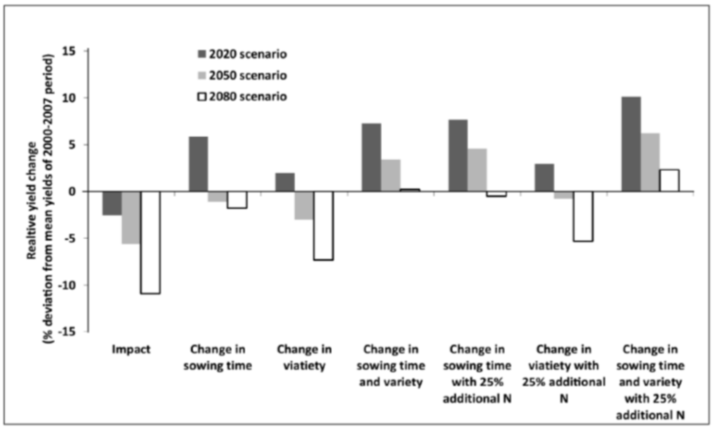

Figure.8 Impact of climate change on potato yield and adaptation gains in 2020, 2050, 2080 scenario.

3.3.4 Effect of nano fertilizers on the productivity and green house gas fluxes in rice cultivation

Impact study of NH_4^+–N loaded nano-zeolite on the growth and green house gas fluxes in rice cultivation under different moisture regimes clearly indicated enhanced nitrogen availability, crop growth in addition to minimizing the emission of methane from rice soils. Due to the combined effect of growth enhancement and lesser methane flux, nitrogen loaded nano zeolite might be a potential and eco-friendly source of N for rice cultivation.

4. Conclusions

Climate change effects on agriculture are likely to be ubiquitous, both in terms of direct and indirect impacts. Maintaining crop yield and health across the country, in turn, is the key requirement for climate change adaptation and mitigation. Through DST research initiatives, available cultivars of rice, maize and wheat were screened for thermal tolerance and various adaptation technologies were also identified for *viz.*, cultivation of rice crop in SRI method, planting the crop in best planting window and application of NH_4^+–N loaded nano-zeolite to enhanced nitrogen availability, crop growth in addition to minimizing emission of methane. To maintain ecosystem services under variable, unpredictable conditions, we need more resilient technologies and upscaling those for the benefit of farmers.

Acknowledgements

The paper has been by and large curved out of the research outcome from a Centre of Excellence and two Major R&D projects supported by DST at ICISAT, Hyderabad; TNAU, Coimbatore and IARI, New Delhi. Many scientists from these institutions were part of these projects. Authors wish to acknowledge contributions from Dr. T.N. Balasubramanian and Dr. A. Lakshmanan of Tamil Nadu Agricultural University, Coimbatore; Dr. A. Bhatia, Dr. Subhash Chander, Dr. T.K. Das, Dr. S. Gopalakrishnan, Dr. S. Naresh Kumar, Dr. Madan Pal, Dr. V.K. Sehgal, and Dr. S.D. Singh of Indian Agricultural Research Institute, New Delhi. Thanks are also due to Dr Susheela Negi, Scientist-D and Dr Rabindra Panigrahy, Scientist-C of Climate Change Programme, SPLICE Division, DST for their support.

References

Annamalai, H., 2010: Moist Dynamical Linkage between the Equatorial Indian Ocean and the south Asian Monsoon Trough. *J. Atmos. Sci*., **67**, 589-610.

Khan S A, Kumar S et al. (2009). Climate change, climate variability and Indian agriculture: impacts vulnerability and adaptation strategies, Climate Change and Crops, Environmental Science and Engineering, 19–38, DOI 10.1007/978-3-540-88246-6 _2.

Rajiv Kumar, C., Joshi, Jaideep, Jayaraman, Mathangi, Bala, G. and Ravindranath, N. H., 2012, “Multi-model climate change projections for India under representative concentration Pathways”, *Current Science*, **103**, 791-802.

Rupa Kumar, K., Krishna Kumar, K., Ashrit, R.G., Patwardhan,S.K., and Pant, G.B., 2002. Climate Change in India Observations and Model Projections, a chapter in NATCOM Book, 'Climate Change and India' edited by P.R.Shukla, Subodh K. Sharma and P.Venkata Ramana, published by *Tata McGrow-Hill Ltd*.,Chapter 2,24-75.